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Model for Predicting In-Stack Response Functions for Beta Attenuation-Based PM CEMS and Proposed Alternatives to PS-11 and P-2 Using a QAG

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Cooper Environmental Service, LLC

10180 SW Nimbus Avenue, Suite J6

Portland, OR 97223

www.cooperenvironmental.com

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Model for Predicting In-Stack Response Functions for Beta Attenuation-Based PM CEMS and Proposed Alternatives to PS-11 and P-2 Using a QAG

Prepared by

Andrea Geiger, Troy Pittenger, Jamie Berg, and John A. Cooper
Cooper Environmental Services, LLC
Portland, OR

and

Craig Clapsaddle
Mechanical Systems, Inc.
Raleigh, NC

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SUMMARY

Recent quantitative aerosol generator (QAG) testing with three independent beta attenuation monitor (BAM)-based particulate matter (PM) continuous emissions monitoring systems (CEMS) has demonstrated strong agreement between predicted QAG reference aerosol concentrations and measured PM CEMS aerosol concentrations based on PM CEMS factory thin film standard calibrations. The average concentration relationship between the QAG (C_{QAG}) reference aerosol concentration and all three of the BAM-based PM CEMS (C_{CEMS}) measurements is given by the following linear equation:

$$C_{QAG} = (1.06 \pm 0.02)C_{CEMS} - 1.43 \pm 0.61$$

The linearity of this relationship over a concentration range from zero to 75 mg/m^3 was strong, as evidenced by a coefficient of determination (R^2) of 0.99. In addition, the uncertainty in the individual slopes was about 2%, while the standard deviation in the mean slope for all three CEMS (1.05 (1A), 1.06 (2B), and 1.07 (3A)) was less than 1%.

Results from Environmental Protection Agency (EPA) Performance Specification 11 (PS-11) for multiple BAM-based PM CEMS showed not only high variability between PM CEMS' calibration slopes, but also a significant departure from the ideal 1:1 linear relationship, with some slopes as high as 3.7. The results from both the QAG and PS-11 testing indicate that off-line QAG calibrations of PM CEMS cannot be used alone to predict in-stack response functions for BAM-based PM CEMS. However, based on this data and theoretical considerations, a model has been developed that suggests that independent off-line BAM-based PM CEMS calibrations using the QAG, in conjunction with measurements of PM CEMS probe deposits at typical stack conditions, can reliably and accurately estimate in-stack PM concentrations. A key concept of this proposed linear model assumes that a PS-11 slope's deviation from 1.0 is due primarily to losses from probe deposits.

Based on this model, alternatives to PS-11 and Procedure 2 (P-2) are outlined that would not require altering plant processes. These alternative specifications and procedures are expected to meet EPA criteria for approval of alternative methods. Results from applying the alternative PS-11 method to existing PS-11 data from 14 coal fired power plants (CFPP) are encouraging. The results demonstrate that the proposed model of incorporating off-line QAG and probe deposit measurements is capable of producing results comparable to PS-11, except the QAG method would not require extrapolation at higher concentrations nor modification of CFPP processes.

Cooper Environmental Services, LLC recommends that these alternatives (performance specification (PS-11B) and an alternative on-going quality assurance procedure (P-2B)) be developed and formalized. Once completed, the alternatives should be submitted to the EPA to solicit their comments and contributions towards the development of a field demonstration plan. It is further recommended that these field demonstration tests be conducted to develop a database to support a request for EPA approval of these proposed alternative methods.

This document presents a conceptual physical and mathematical model approach for determining in-stack response functions. In addition, outlines of alternatives to EPA's PS-11 for initial certification and calibration and EPA's P-2 for on-going quality assurance of BAM-based PM CEMS are presented. Also presented here are discussions of the data and theoretical considerations to support model conclusions and proposed alternative procedures.

1.0 Introduction

Recent EPA regulations for electric generating units (EGUs) require plant operators to limit emissions of hazardous air pollutant (HAP) metals. Operators have several paths for demonstrating compliance under this new regulation. One of the preferred compliance demonstration paths is to monitor total PM emissions with a PM CEMS as an EPA-accepted surrogate for HAP metals emissions. Initial PM CEMS certification with performance specification 11 (PS-11) and on-going QA with procedure 2 (P-2) are difficult, costly, and are typically unable to establish an adequate linear operating range. Cooper Environmental Services LLC (CES) has developed a quantitative aerosol generator (QAG) similar to reference gas generators and certified reference calibration gas cylinders. CES' QAG has been proposed as a reference aerosol source that could be used in alternative performance specifications and on-going QA procedures, which would be easier to implement, less costly, and provide a larger dynamic range of validated linearity. Using a QAG in an alternative certification and/or on-going QA procedure would most likely require off-line calibration of a candidate CEMS with a QAG-generated aerosol and then infer an in-stack CEMS response function from these off-line QAG-based calibrations.

Results from recent QAG field tests with BAM-based PM CEMS provided encouraging results that support the potential of this off-line calibration approach (Pittenger et al., 2012). For example, in these recent field tests, a QAG-generated reference aerosol challenged three previously PS-11 certified BAM-based PM CEMS off-line by comparing predicted QAG reference concentrations to reported PM CEMS concentrations, and by comparing the QAG-/CEMS-based regression parameters to PS-11-/CEMS-based regression parameters. The average concentration relationship between all three of the PM CEMS (C_{CEMS}) and the QAG (C_{QAG}) concentration measurements is given by the following linear equation:

$$C_{QAG} = (1.06 \pm 0.02)C_{CEMS} - 1.43 \pm 0.61.$$

The linearity of the QAG/PM CEMS relationship over the concentration range from zero to 75 mg/m^3 was strong, as evidenced by a coefficient of determination (R^2) of 0.99. In addition, the uncertainty in the individual slopes was about 2%, while the standard deviation in the mean slope for all three CEMS (1.05 (1A), 1.06 (2B), and 1.07 (3A)) was less than 1%. This high level of agreement is even more impressive when one considers that the PM CEMS factory calibration is based on thin film standards, while the QAG-predicted concentrations are based on NIST-traceable components and in-field determination of transport efficiency. The independent nature of the QAG's predicted concentration and the PM CEMS' measured concentration supports the high accuracy, precision, stability, and reproducibility of **both** the QAG and the PM CEMS. As evidenced by the data, these three PM CEMS' sensors, which have been in operation for about three years, provide an accurate measure of PM mass captured on the CEMS filter tape.

The linearity of the relationship between these three PM CEMS and EPA Method 5B (M5B) was also quite good with a coefficient of determination of 0.99. However, although the off-line response functions for the three BAM-based PM CEMS were nearly identical, the in-stack slopes measured with

M5B for these same three PM CEMS were 1.17 (CEMS 1A), 1.19 (CEMS 2B), and 1.63 (CEMS 3A) with an average slope uncertainty of about 4%. Although the slope uncertainty as determined with M5B is higher than that obtained with the QAG (4% versus 1%), the more important issue is why these three nearly identical PM CEMS and off-line QAG response functions are reporting such significantly different slopes with M5B compared to the QAG.

The difference between in-stack and off-line response functions is particularly important for the development of alternatives to PS-11 and P-2 based on off-line QAG measurements. For example, any off-line measurements with the QAG would have suggested similar in-stack response functions, whereas the PS-11/M5B data show the in-stack response functions are clearly different, and quite significantly for the CEMS exhibiting a slope of 1.63. It is important to note that this high slope (1.63) is not an outlier; on the contrary, numerous other high slopes have been reported (Mechanical Systems, Incorporated (MSI), BetaGuard PM CEMS data, presented in Subsection 2.3 of this report) for this same type of PM CEMS, with one slope as high as 3.7. It can be assumed from the results of the three BAM-based PM CEMS tested that off-line QAG calibration for these other BAM-based PM CEMS would be similar to the QAG-determined slope values. Additionally, these measurements (QAG, CEMS, and M5B) can be considered to be precise, independent (NIST, thin film, reference method), and accurate measurements and predictions of PM concentration. Furthermore, these recorded differences between slopes are real and statistically significant with, in some cases, differences exceeding well over five standard deviations in the slope measurements. As such, these differences need to be well understood before an alternative method to PS-11 and P-2 can be developed based on off-line QAG measurements and proposed to the EPA.

The objective of this work is to develop alternative procedures to PS-11 and P-2 based on off-line PM CEMS reference aerosol measurements, such as those generated by a QAG. The objective of this specific document is to provide a foundation for further discussions of how the QAG might be used in this capacity. Our approach to this problem has been to first develop conceptual physical and mathematical models to explain the results from these three independent measurements and understand why the data fit a linear model so well. Then, based on this new understanding, we propose an alternative performance specification and procedure that uses off-line measurements in conjunction with probe- and transport-loss measurements. Section 2.0 reviews the details of these recent QAG/PM CEMS/M5 test results and their implications. In Section 3.0, physical and mathematical models are proposed that form the foundation for understanding the current field data and the development of alternatives to PS-11 and P-2. Based on this new understanding, preliminary outlines of alternatives to PS-11 and P-2 are proposed and discussed in Section 4 followed by considerations of implications, recommendations, and conclusions.

2.0 Review of Recent BAM-Based Test Results

2.1 Background for CEMS, Testing, and Power Plant

2.1.1 Bruce Mansfield Power Plant

The BAM-based PM CEMS testing occurred near Shippingport, Pennsylvania at the Bruce Mansfield Power Station (BMPS), which is a coal-fired power plant owned and operated by First Energy. BMPS has three pulverized coal-fired boilers producing 835 megawatts (MW) each, for a combined site total of 2505 MW. It is the largest coal plant owned and operated by First Energy. At full capacity, the plant's generating units can produce 56-million kilowatt-hours of electricity daily.

Units 1 and 2 exhaust through a 950-foot stack and are equipped with several emission controls, including a wet venturi scrubber for sulfur dioxide (SO_2) and PM controls, low- nitrogen oxide (NO_x) burner/separated over-fired air integration system (LNB/SOFA), selective catalytic control, and a sodium bisulfite injection system. Unit 3 exhausts through a 600-foot stack and is controlled with an electrostatic precipitator (ESP), followed by a horizontal weir wet scrubber for PM and SO_2 control. It is also equipped with an LNB/SOFA, selective catalytic control, and a sodium bisulfite injection system (Hatch, 2012). Each unit has two exhaust flues with a PM CEMS located on each flue. The QAG was interfaced with one CEMS from each unit (1A, 2B, and 3A). Units 1 and 2 both have a typical PM level between 15 and 25 milligrams per wet standard cubic meter (mg/wscm); the stack gas is not saturated with water. Unit 3 has a typical PM level between 5 and 15 mg/wscm and is saturated with free water droplets.

2.1.2 BAM-based PM CEMS

The PM monitors tested at BMPS were MSI BetaGuard PM CEMS. The primary components of a BetaGuard PM CEMS include a probe and transport system to deliver a representative PM sample to a reel-to-reel filter tape sampler. The measured flow through the filter tape and the PM mass deposited are measured and used to calculate the stack gas PM concentration. The principle behind BAM-based PM CEMS is that the intensity of a beam of beta particles is reduced as it passes through PM collected on a filter media. A baseline beta intensity of blank filter media is collected and compared to the beta intensity after sample collection. The attenuation of beta ray intensity between the baseline and post-sample filter provides a measure of the PM deposit mass.

MSI BetaGuard CEMS are capable of measuring on a wet or dry basis and have dual carbon-14 (^{14}C) beta sensor designs, a seven-point thin film factory beta calibration, a four-point flow calibration, and automatic daily beta and flow calibration checks. The three PM CEMS tested were all installed and PS-11 certified about three years prior to QAG testing and each CEMS met all on-going QA requirements defined in P-2. The PM CEMS' sampler (reel-to-reel tape drive) and mass sensor (beta source and detector) are located between 45 (1A) and 80 (2B, 3A) feet away from the probe outlet, which were identical for all three CEMS. A P-2 response correlation audit (RCA) for CEMS 1A and 2B was performed before the QAG testing of those PM CEMS, and a P-2 relative response audit (RRA) for CEMS 3A was performed after QAG testing. All P-2 criteria were met for all three of the PM CEMS tested.

2.2 Testing Results at the Bruce Mansfield Power Station

2.2.1 PS-11 Results

Results from initial PS-11 certification tests for the three PM CEMS of interest (1A, 2B, and 3A) are summarized below in Table 1. These results show a very linear relationship (R^2=0.992, 0.983 and 0.981) between the PM CEMS factory calibration concentration and the M5-measured PM concentration; all three CEMS met PS-11 initial certification test criteria. The slopes for 1A and 2B CEMS correlations are similar (1.17 ±0.02 and 1.19 ±0.02) and within one standard deviation of each other. However, the PS-11 correlation slope for CEMS 3A is significantly different (1.63 ± 0.053) from the first two PM CEMS, and all three are statistically different from 1.00 by well over five standard deviations. It is generally thought that this divergence from one is due to differences between the thin films used to calibrate the PM CEMS sensor in the factory and such factors as in-stack aerosol characteristics, probe location, particle losses in sampling system, etc. (Jahnke, 2000). The EPA considers these differences are compensated for by using the in-stack calibration based on simultaneous M5 and PM CEMS concentration measurements, as defined in PS-11. As discussed in this report, we hypothesize that deviations in slope from 1.00 are due primarily to PM losses (deposits) in the probe and transport before the PM aerosol reaches the filter tape and beta gauge sensor, while most of the other possible influencing variables contribute primarily to the systematic constant bias term or random variability, i.e. data scatter.

Table 1. Summary of initial PS-11 Certification correlation test results for the three PM CEMS challenged by the QAG (1A, 2B, 3A)

CEMS ID	**1A**			**2B**			**3A**		
Parameter									
R^2 (CoD)	0.992			0.983			0.982		
m (slope)	1.17	±	0.025	1.19	±	0.043	1.63	±	0.054
b (intercept)	0.32	±	0.500	-2.04	±	0.962	-1.17	±	0.532
COL (mg/wscm)	45.6			62.5			38.0		

CoD = Coefficient of Determination; COL = Continuous Operating Limit

2.2.2 P-2 On-Going Results

As noted above, the initial PS-11 certification test results were strongly linear. In addition, the on-going P-2 QA test results were within linear confidence intervals, as illustrated in Figure 1a through 1c, where original PS-11 correlation data (black diamonds) are compared to subsequent P-2 data for RRA (red squares and blue triangles), and RCA (black circles) tests conducted since initial installation and certification. All of the P-2 data fit well within EPA-accepted correlation regression line limits (dashed red lines; ± 25% of the numerical emission limit value from the correlation regression line) and were within EPA-defined tolerance and confidence intervals. These graphs show that these CEMS remained stable and precise over a period of several years. They were also operating well, and in compliance, at the time of and immediately following the QAG tests as evidenced with the successful RRA and RCA tests.

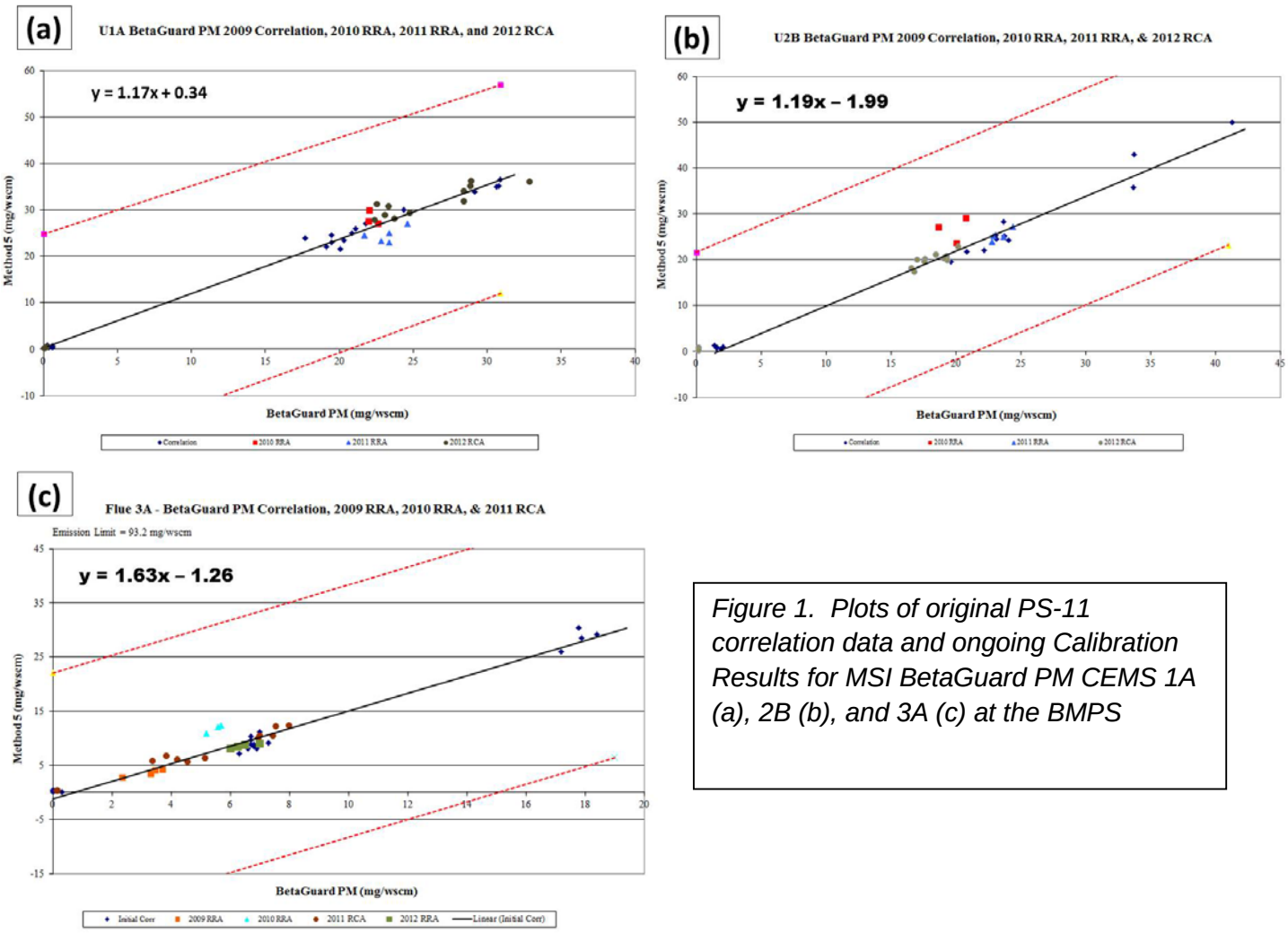

Figure 1. Plots of original PS-11 correlation data and ongoing Calibration Results for MSI BetaGuard PM CEMS 1A (a), 2B (b), and 3A (c) at the BMPS

2.2.3 QAG Testing Results

The three BMPS operating PM CEMS were taken off-line and challenged with QAG-generated, NIST-traceable aerosols of known concentrations. The results of this comparison (QAG-predicted concentration versus PM CEMS measured concentration) are summarized in Table 2 and Figure 2. These results show very similar correlation parameters for all three of the CEMS with a strong linear relationship (R^2 >0.985) up to about 75 mg/m^3. The average concentration relationship between the three PM CEMS (C_{CEMS}) and the predicted QAG (C_{QAG}) concentration is given by the following linear equation:

$$C_{QAG} = (1.06 \pm 0.02)\, C_{CEMS} - 1.43 \pm 0.61 \qquad \textit{Equation 1}$$

This linear equation is an average of QAG testing of three BAM-based PM CEMS; summarized in Table 2 below:

Table 2. Summary of CEMS correlation parameters resulting from QAG measurements

PM CEMS ID	1A			2B			3A		
Parameter									
R^2 (CoD)	0.985			0.994			0.993		
m (slope)	1.077	±	0.04	1.054	±	0.025	1.063	±	0.024
b (intercept)	-3.103	±	1.483	-1.391	±	1.01	-0.281	±	0.955

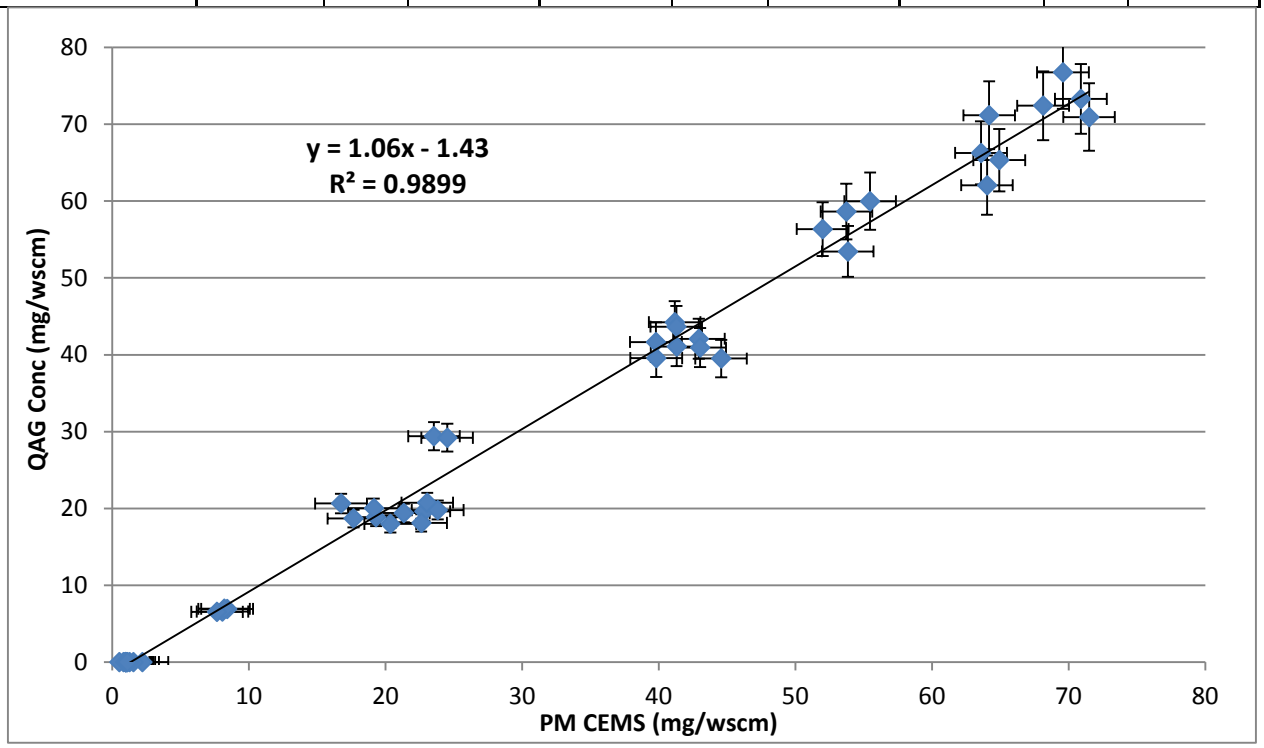

Figure 2. Plot of predicted QAG reference aerosol concentration versus measured concentration by three different BAM-based PM CEMS exhibiting a highly linear relationship and a slope close to one

The linearity of the relationship over the concentration range from zero to 75 mg/m^3 was very strong, as represented by a coefficient of determination (R^2) of 0.99. The uncertainty in the individual slopes was about 2%, while the uncertainty in the mean slope was less than 1%. As previously mentioned, this level of agreement is very impressive, considering that the CEMS factory calibration is based on thin film standards, while the QAG-predicted concentrations are based on NIST-traceable components and in-field determination of transport efficiency. The linearity of the relationship between the PM CEMS and EPA M5B was also quite good, with a coefficient of determination of 0.99, but the slopes for these same three PM CEMS were 1.17, 1.19 and 1.63 with an average slope uncertainty of 2 to 4%. Although the slope uncertainty, as determined with M5B, is higher than that obtained with the QAG, the more important issue is why these three, nearly identically performing PM CEMS and response functions are reporting significantly different slopes with M5B compared to the QAG and thin film-based PM CEMS

calibrations. As noted previously, the primary contribution to correlation slopes that deviate from one in this BAM-based PM CEMS application is hypothesized to be due to probe and transport loss of PM prior to being sampled and measured with the filter tape and beta gauge.

2.3 Comparison of QAG and PS-11 Results

A difference in slopes between the QAG- and PS-11-calibration results is seen in the data presented in sections 2.2.1 through 2.2.3. This difference is particularly important for the development of alternatives to PS-11 and P-2 based on off-line QAG measurements. For example, any off-line measurements with the QAG would have suggested similar in-stack response functions (similar slopes within a few percent), whereas the PS-11 data clearly show the in-stack response functions are significantly different for CEMS 3A, which exhibited a slope of 1.63 ± 0.05. It is important to note that this high slope (1.63) is not an outlier. On the contrary, numerous other high slopes have been reported for this same type of BAM-based PM CEMS (MSI BetaGuard), one of which exceeded three, as shown in Table 3. Based on the stability and reproducibility of the three BMPS PM CEMS tested with the QAG, it can he assumed that off-line QAG calibrations for these latter CEMS would have been similar to the 1.06 measured with the QAG. It can also be drawn from these measurements (QAG, CEMS, M5B) that each instrument/method is a precise, independent (NIST-QAG, thin film-CEMS factory calibration, M5B), and accurate measurement/prediction of PM concentration. In addition, it can be concluded that these recorded slope differences, which in some cases exceed the ideal linear slope of one by well over five standard deviations, are real and statistically significant. As such, these differences need to be well understood before an alternative method to PS-11 and P-2, based on off-line QAG measurements, can be proposed to the EPA.

Table 3 lists correlation parameters from a comparison of concentrations measured by factory-calibrated MSI BetaGuard PM CEMS and Reference Methods 5 or 5B simultaneously. Examples 13 through 15 show the resulting slopes from PS-11-calibrated CEMS at BMPS, while 16 through 18 show the resulting slopes from the same BMPS PM CEMS when calibrated with the QAG. Overall, the QAG-calibrated CEMS results depict more strongly correlated data based on the R^2 values, as well as slopes that are closer to a 1:1 ratio in CEMS response.

The graphs shown in Figures 3a through 3c provide side-by-side comparison of the correlation plots and best-fit linear regression parameters for the three BMPS PM CEMS tested with both PS-11 and the QAG.

Our approach to the problem arising from such statistically different results for the same PM CEMS, despite the apparent stability and precision of each respective method's measurements, has been to first develop a conceptual physical model (described in Section 3.0) to explain the results from these three independent measurements and understand why they fit a linear model so well, while being so statistically different. Then, based on this new understanding, outlines of alternative performance specifications and procedures that use off-line measurements are suggested and discussed.

Table 3. Comparison of Linear Model Fit Parameters for Fifteen BAM-Based PM CEMS Developed with PS-11 In-Stack or QAG Off-line Measurements (MSI BetaGuard data)

Example	Slope ± Uncertainty	Intercept ± Uncertainty	R^2	% Slope Uncertainty	Notes*
1	2.053 ± 0.095	+ 0.437 ± 0.203	0.971	4.6	IS
2	2.297 ± 0.083	+ 0.848 ± 0.240	0.982	3.6	IS
3	1.100 ± 0.082	+ 0.376 ± 0.159	0.864	7.5	IS
4	1.805 ± 0.042	+ 1.024 ± 0.555	0.991	2.3	IS
5	1.263 ± 0.107	- 0.809 ± 0.280	0.914	8.5	IS
6	1.462 ± 0.045	- 2.689 ± 0.871	0.988	3.1	IS
7	1.529 ± 0.058	- 0.222 ± 0.291	0.977	3.8	IS
8	2.665 ± 0.134	- 0.923 ± 0.852	0.957	5.0	IS
9	1.355 ± 0.088	- 0.493 ± 0.901	0.919	6.5	IS
10	1.488 ± 0.054	- 0.298 ± 0.545	0.977	3.6	IS
11	3.702 ± 0.125	- 0.820 ± 2.582	0.983	3.4	IS
12	1.844 ± 0.114	+ 0.058 ± 1.175	0.945	6.2	IS
13 (1A - PS-11)	1.166 ± 0.025	+ 0.322 ± 0.501	0.992	2.1	IS
14 (2B - PS-11)	1.190± 0.043	- 2.043 ± 0.962	0.983	3.6	IS
15 (3A - PS-11)	1.625 ± 0.054	- 1.170 ± 0.532	0.982	3.3	IS
16 (1A - QAG)	1.077 ± 0.036	- 3.103 ± 1.483	0.985	3.3	OL
17 (2B - QAG)	1.054 ± 0.025	- 1.3591± 1.01	0.994	2.4	OL
18 (3A - QAG)	1.063 ± 0.024	- 0.81 ± 0.955	0.993	2.3	OL

* IS = In-Stack; OL = Offline

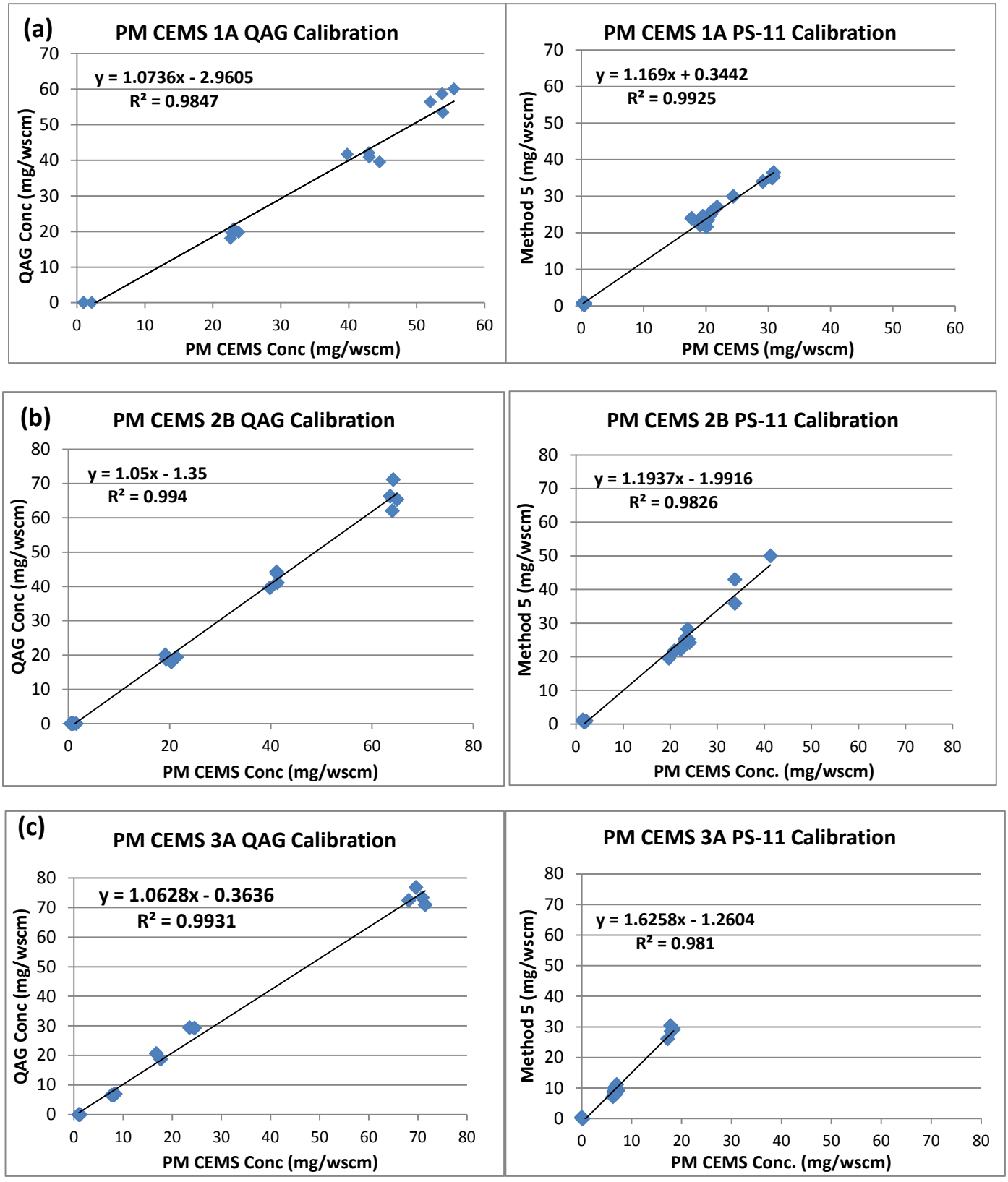

Figure 3. Comparison of PS-11/PM CEMS and QAG/PM CEMS response functions for 1A (a), 2B (b) and 3A (c) PM CEMS at the BMPS.

3.0 Proposed Models

3.1 Overview

As discussed in this report, alternatives to EPA's PS-11 and P-2 are needed. Although off-line calibration of PM CEMS with an independent reference aerosol generator like the QAG holds great promise, off-line QAG calibrations have not demonstrated distinct applicability to in-stack response functions for BAM-based PM CEMS (CES 2012). Although the data presented in Section 2.0 for BAM-based PM CEMS like the BetaGuard are encouraging, the differences between off-line and in-stack calibrations are large relative to the statistical uncertainties. The factors responsible for these statistically significant differences need to be understood before reliable alternatives to PS-11 and P-2 can be developed, and before they are likely to be accepted by the EPA. One possible starting point for understanding the causes of these observed differences is to posit a physical model describing the physical parameters that might influence the system being measured (stack gas PM aerosol), the measurement systems (M5, M5B, CEMS), and statements of assumptions implicit in a theoretical mathematical model, as described in Section 3.2. Following the physical model description, we present a linear mathematical model that defines BAM-based PM CEMS data variability and a discussion of how this physical model influences the correlation parameters, the consistency of field measurements with the model, and model implications.

3.2. Physical Model

A simplified physical model of our system is schematically illustrated in Figure 4. This system includes not only the measurement systems, but also the system being measured since variability in both can contribute to observed variability in aerosol PM concentration.

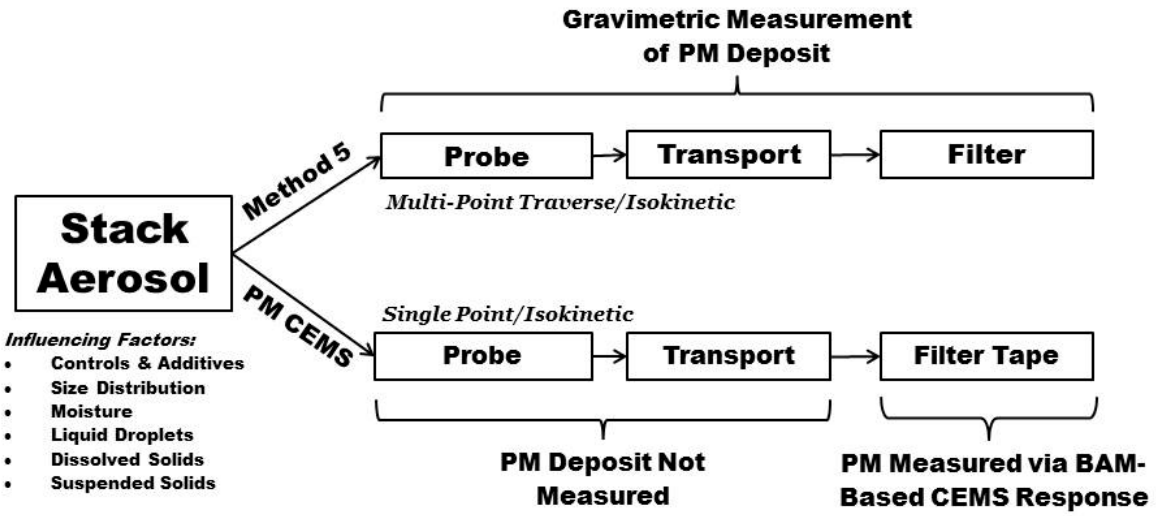

Figure 4. Schematic illustration of proposed physical model of the PM deposit measurements for both EPA Reference Method 5 and extractive BAM-based PM CEMS

Stack gas PM aerosols consists of a suspension of liquid and solid particles of varying size and composition traveling at high velocities (typically 30 to 50 mph), at relatively high temperatures (about

150° to 350°F) and moisture conditions that range up to super-saturation. These conditions can be relatively dynamic, with mass being exchanged between phases, and can be strongly influenced by a range of process operations including fuel type, combustion characteristics, emission controls, additives, etc. However, in the case of coal-fired power plants, these conditions are generally maintained relatively constant so as to assure optimum operational efficiency while consistently meeting required emission limits. These aerosol characteristics are important because they can affect PM CEMS sampling and transport efficiency as well as contribute to potential measurement artifacts.

The objective of both EPA M5 and PM CEMS is to measure the "true" stack PM concentration. In the case of M5, a traverse of the stack is conducted while an isokinetic sample of known flow (volume) is drawn through a nozzle, probe, filter and flow monitor. Although a substantial portion of the PM may be deposited in the probe, this deposit is recovered as part of the M5 procedure and added to the PM deposited on the filter. This total PM mass is divided by the volume sampled to calculate the stack gas PM concentration, which, by definition, is assumed to be the "true" stack concentration. Although the reference method is good, it is not a perfect measure of the "true" stack concentration. The M5 reported results are only an estimate of the true stack gas concentration. The reference method (M5) will have to varying degrees both systematic and random uncertainties associated with each estimate of the true concentration due to such variables as local turbulence, deviations from isokinetic sampling conditions, errors in pitch and yaw, flow uncertainties, less than 100% PM recovery from the probe, acid filter artifacts, sample handling, contamination, etc.

The PM CEMS also attempts to collect a representative sample of the stack gas by collecting an isokinetic sample, but from a single point in the stack that has been generally selected to represent the mean traverse concentration. The PM aerosol is transported through a probe and transport component before it is drawn through a filter tape where the PM is deposited and its mass measured with a beta attenuation sensor. Although some PM mass is deposited in the CEMS probe and transport components, it is not recovered, but is periodically purged from the sampling line with a "blow back" step. These PM CEMS limitations are well recognized by the EPA, which is one reason why the EPA insists on calibrating PM CEMS with in-stack M5 measurements as part of PS-11. Implicit with this calibration requirement is the assumption that aerosol features that might affect PM deposition in the CEMS probe are constant with time. There are, of course, other systematic bias and random errors that can contribute to the uncertainties and variability of both M5 and PM CEMS measurements, as well as process changes, that can vary the characteristics of the aerosol and subsequently the quantity of PM CEMS probe deposition.

What is clear from this simplified physical model and the QAG/PM CEMS results summarized in Section 2.0 is that the PM CEMS beta attenuation sensor provides an accurate, precise, and reproducible measure of mass deposited on the CEMS' filter tape. And, although the in-stack aerosol conditions might be significantly different from the off-line QAG aerosol, the BAM-based PM CEMS' mass sensor does not detect this difference, because it does not come in direct contact with the aerosol, but only quantifies the mass deposited on the filter tape. Consequentially, it is reasonable to assume 1) the operation of the beta attenuation sensor functions the same under QAG aerosol conditions as under stack gas sampling conditions and 2) differences in BAM-based PM CEMS comparisons between the QAG

off-line measurements and M5 in-stack measurements are due primarily to differences up-stream of the BAM-based PM mass sensor, assuming a representative sampling location in the stack is chosen. For the PM CEMS, these might include differences in probe and transport conditions such as nozzle diameter, yaw, pitch, and temperature; transport tubing diameter, length, polish, and bends; sampling flow rate; filter tape sampling efficiency and chemistry. Stack conditions might include stack gas characteristics such as moisture content, PM size distribution, free acid content, presence or absence of droplets, and gas temperature. Plant conditions might include plant processes and controls, operating conditions, additives, scrubber solution chemistry, coal type, de-mister efficiency, etc.

Thus, the conceptualized physical model that forms the foundation of our attempts to understand the contributors to differences in off-line QAG calibrations of PM CEMS and in-stack M5 calibrations of these same PM CEMS is a simplified model composed of five major components:

- PM CEMS beta attenuation sensor
- PM CEMS sampling and transport
- Stack gas aerosol properties
- QAG aerosol
- Reference Method

These will be discussed in the following subsection as they impact the mathematical form and components of the linear calibration equation.

3.3 Mathematical Model

It is clear from the data presented in Section 2.0 that the relationship between the QAG-predicted concentration, the BAM-based PM CEMS measured concentration, and the M5 measured concentration is linear as illustrated by the plots presented in Figure 3 and data in Table 3. The mathematical form of the classical slope/intercept form is noted below in Equation 2:

$$Y = mX + b \qquad \textit{Equation 2}$$

where Y is the QAG-predicted aerosol concentration or M5 measured concentration, m is the slope (representing influence of variables proportional to X), X is the BAM-based PM CEMS measured concentration, and b is the intercept (representing the influence of constants independent of X).

As noted in Section 2.0, most of the variability in the data is driven by the variability in the concentration and there is minimal variability associated with general data scatter as evidenced by the high observed coefficient of determination ($R^2 = 0.99$). In addition, the variability between the slopes is large (1 to 3.7) relative to the statistical uncertainty (about 0.05) in the slope measurement, while the variability in the intercept (1 to 3) is large relative to its statistical uncertainty (about 1). As such, the primary focus is on the slope and the variables that are likely responsible for differences between slope measurements (calibration factors) made with a QAG-generated aerosol, as compared to slope measurements made with in-stack M5 measurements of stack gas aerosols. The primary objective of

this section is to review those parameters that are likely to have significant impacts on the slope and intercept, and relate them to this linear model.

As noted above, the true PM concentration (C_{true}) can be expressed as a function of the reported M5 concentration (C_5), plus or minus a systemic bias (C_5^B) and random (C_5^R) uncertainty or error terms, as noted below in Equation 3:

$$C_{true} = C_5 \pm C_5^B \pm C_5^R \qquad \textit{Equation 3}$$

Similarly, the true PM concentration can be expressed as a function of the reported PM CEMS concentration (C_C), its known and unknown bias and random uncertainties or errors, as noted below in Equation 4:

$$C_{true} = C_C + C_c^{PD} - C_c^{AAB} \pm C_c^{SPB} \pm C_c^{OUB} \pm C_c^R \qquad \textit{Equation 4}$$

Where:

C_c^{PD} is the concentration bias due to PM deposited in the probe and transport line

C_c^{AAB} is an acid artifact bias due to vapor phase acids reacting with a basic filter

C_c^{SPB} is a single point bias *(Assumption: SPB minimized by selecting a CEMS sampling point close to traverse average concentration)*

C_c^{OUB} is other unknown bias

C_c^R is concentration error associated with random measurement variability

Combining Equations 3 and 4, and solving for the M5 reported concentration (C_5), we obtain the following equation:

$$C_5 = C_C + C_c^{PD} - C_c^{AAB} \pm C_c^{SPB} \pm C_c^{OUB} \pm C_c^R \pm C_5^B \pm C_5^R \qquad \textit{Equation 5}$$

The terms on the right side of Equation 5 can be grouped into three categories as indicated in Equation 6 below:

$$C_5 = \left[C_C + C_c^{PD}\right] + \underbrace{\left[-C_c^{AAB} \pm C_c^{SPB} \pm C_c^{OUB} \pm C_5^B\right]}_{\mathbf{B}} \pm \underbrace{\left[C_c^R \pm C_5^R\right]}_{\mathbf{R}}$$

If we assume that probe and transport losses are proportional to PM CEMS reported concentration ($C_c^{PD} = kC_C$), where k equals a constant value, the bias terms ($C_c^{AAB} \pm C_c^{SPB} \pm C_c^{OUB} \pm C_5^B$) are assumed to be nearly constant, and the third category $\left[C_c^R \pm C_5^R\right]$ contains random variables for both the CEMS and M5; Equation 6 can be simplified to the following classic linear relationship:

$$C_5 = \underbrace{(1+k)}_{m} C_c + B \pm R \qquad \textit{Equation 7}$$

The random component of variability ("R") in Equation 7 is actually a function of both the concentration (C_c) and constant bias (B) terms. It is important to note that the probe and transport losses are proportional to concentration only to a degree, but, in fact, may also be a function of such variables as particle size distributions, dissolved and suspended solids in droplets downstream of wet scrubbers, and other factors affecting the nature of the stack gas aerosol. In a perfect world $C_C = C_{true} = C_5$ where m = 1, k = 0 and B = 0. More realistically, k and B are not equal to zero and m = 1+k. One can thus conclude that the slope of the in-stack PM-CEMS response function can be estimated from a measurement of the probe and transport PM deposit relative to the CEMS-measured PM concentration (C_c^{PD}/C_C); that is m=1+C_c^{PD}/C_C.

3.4 Model Evaluation

As noted above, a number of variables can influence the measured PM aerosol concentration. It is important to estimate the magnitude of the more significant potential variables. Examples of these variables and the magnitude of their potential range of impact are listed in Table 4. The CEMS and M5 measured concentrations in EGU emissions are expected to range from about 1 to 100 mg/m^3. BAM-based PM CEMS probe deposits are expected to have the largest influence on deviations from true concentration measurements and are expected to range from 10 to about 75% of the "true" concentration based on the measured slopes (Table 3) and the above discussed model. Acid artifacts (vapor phase acid reactions with glass fiber filters) represent an example of a variable that is likely to be relatively constant, independent of the PM concentration and have a magnitude less than about 5% of the PM concentration. Although this potential acid artifact could be a higher percentage for sources with lower PM concentrations, these lower PM concentrations are typically achieved with wet scrubbers which also remove most of the acids that are likely to react with BAM-based PM CEMS filter tapes. The single point bias is expected to be small, in part because large differences in PM are not expected in the stack at the point where measurements are made, but also because the point selected for the probe nozzle is selected to minimize this difference. As such, its magnitude is expected to be substantially less than about 5%. Other BAM-based PM CEMS biases are expected to be small because the QAG test bias was small for all three of the BAM-based PM CEMS. Method 5 bias is also expected to be small in part because it is a reference method. Random errors associated with the CEMS, M5 and QAG are expected to be small based on the small amount of data scattered and high coefficient of determination observed in the regression plots. Based on these estimates, it seems reasonable to assume/conclude that measured M5/BAM-based PM CEMS regression slopes greater than 1 are an indicator of the primary influence of probe deposits. Thus, in-stack BAM-based PM CEMS response functions might be estimated either by 1) measuring probe deposits directly or 2) by comparing simultaneous M5 and PM CEMS in-stack concentration measurements at typical or normal operating conditions, or 3) by eliminating or minimizing these losses.

Table 4. Examples of potential variables influencing measured PM CEMS concentration and their potential range

	Variable		CEMS Correction	Percent of PM Concentration	Expected Range (mg/m^3)	Notes
1	Method 5	C_5	-	---	1-100	Expected for Coal-Fired Utility Boilers
	CEMS	C_c	-			
2	CEMS, Probe Deposit	C_c^{PD}	(+)	10 - 75%	0.01→75	Fraction of C_c lost in the probe during sampling transport
3	CEMS, Acid Artifact Bias	C_c^{AAB}	(-)	<5%	0.1→5	Function of filter and acid concentration
4	CEMS, Single Point Bias	C_c^{SPB}	(±)	<5%	<0.01→5	Correction in PM concentration expected to be proportional, but small
5	CEMS, Other Unknown Bias	C_c^{OUB}	(±)	<5%	<0.01→5	Other unknown bias, should be small because QAG difference is small
6	Method 5, Bias	C_5^B	(±)	<5%	<0.01→5	Bias is expected to be small because M5 is a federal reference method
7	CEMS, Random error	C_c^R	(±)	<5%	<0.01→5	Random CEMS error, such as tape position and counting statistics, are expected to be small and independent of concentration
8	Method 5, Random error	C_5^R	(±)	<10%	<0.01→10	Random uncertainties in flow, isokinetic sampling, PM recovery, mass determination, etc.

The influence of probe loss on the in-stack response function can be seen in the data from the 15 BAM-based PM CEMS listed in Table 3. The PM CEMS/M5 regression data has been re-ordered according to increasing slope in Table 5. Additional details regarding the CEMS transport characteristics, PS-11 correlation technique, Plant/EGU emission controls have been added, as they might impact either the in-stack aerosol characteristics or CEMS probe and transport loss. The deposition and aerosol characteristics are ranked based on their potential to and/or likelihood of deposition in the probe and transport components prior to reaching the filter tape and BAM sensor. Generally speaking, an increase in deposition and aerosol characteristic ranking is assumed with an increase in slope. Although this is not a perfect correlation, it is supportive of the model discussed earlier in this section where the slope is dominated by the fraction of PM deposited in the probe and transport. *(Note: this paragraph will be edited pending the addition of data in Table 5)*

Table 5. Comparison of Linear Model Fit Paramenters (In Order from Smallest to Largest Slope) for Fifteen BAM-Based PM CEMS Correlated with M5 and PS-11 In-Stack Measurements

Ex.	m	CEMS Transport Characteristics		Dep. Rank [a]	PS-11 Correlation, Mid/High PM Conc. Technique	Plant Charactertistics		Plant Emission Control			Aerosol Rank [d]
		Probe (d/L)	Transport (d/L)			Coal Type [b]	Saturated?	System(s) [c]	Additives	Demister?	
3	1.100				Varying unit load	Bitu		ESP, SCR, WFGD, WESP	NH_3 or $CO(NH_2)_2$, lime		
13	1.166		___ / 45'			Pulv	No	SCR, LNB, SOFA, SBS, WVS	NH_3, $NaHSO_3$, lime		
14	1.190		___ / 80'			Pulv	No	SCR, LNB, SOFA, SBS, WVS	lime, NH_3, $NaHSO_3$		
5	1.263				Slight ESP detuning	PRB		ESP, SCR, WFGD	NH_3, lime		
9	1.355				ESP detuning, Paired trains	Bitu		ESP, SCR, WFGD	NH_3, lime		
6	1.462				ESP detuning	Bitu		ESP, SCR, WFGD	NH_3, lime		
10	1.488				ESP detuning	Bitu		ESP, SCR, WFGD	NH_3, lime		
7	1.529				Baghouse detuning	Bitu		BH, SCR, WFGD, WESP	NH_3, lime		
15	1.625		___ / 80'			Pulv	Yes	ESP, SCR, LNB, SOFA, SBS, HWS	NH_3, lime, $NaHSO_3$		
4	1.805				ESP detuning	Bitu & PRB		ESP, SCR, WFGD	NH_3, lime		
12	1.844				ESP detuning	LSSB		ESP	-		
1	2.053				B3 Injection of plant ash upstream of ID fan	Waste		SCR, BH	NH_3, Plant Ash		
2	2.297				B3 Injection of plant ash upstream of ID fan	Waste		SCR, BH	NH_3, Plant Ash		
8	2.665				ESP detuning, Paired trains	Bitu		ESP, SCR, WFGD	NH_3, lime		
11	3.702				ESP detuning	LSSB		ESP w/ SO_3 injection	-		

Ex. = Example number, same as shown in Table 3.

m = slope for PS-11 calibration results, shown in Table 3 of this report

CEMS = Continous Emissions Monitoring System

d / L = diameter / Length

a. Deposition ranking is a subjective rating tool to illustrate the likelihood of deposition onto probe and transport lines due to the characteristics of the CEMS, a ranking of '10' being highly likely and a ranking of '1' being unlikely. Examples of parameters which might determine the ranking are as follows: probe / transport diameter, probe / transport length, number of bends in the system, and the aerosol's velocity.

b. Bitu = bituminous, Pulv = pulverized, PRB = Powder River Basin Coal, LSSB = Low Sulfur, Sub-Bitominous.

c. SCR = Selective Catalytic Reduction, ESP = Electrostatic Precipitator, WFGD = Wet Flue Gas Desulfurization, WESP = Wet Electrostatic Precipitator, WVS = Wet Venturi Scrubber, LNB = Low Nitrogen Oxide Burner, SOFA = Separate Over-Fired Air, SBS = Sodium Bisulfate Injection System, HWS = Horizontal Weir Scrubber.
Units are listed in estimated order of emission control process.

d. Aerosol ranking would be a further subjective rating tool to illustrate the likelihood of deposition onto probe due to the type of aerosol, a ranking of '10' being highly likely and a ranking of '1' being very unlikely. Saturated aerosols resulting from the use of wet scrubbers, for example, would be more likely to deposit due to the high presence of dissolved solid droplets and water and therefore would receive a high rating.

4.0 Proposed Alternatives to PS-11 and P-2

4.1 PS-11 and P-2

PS-11 establishes procedures and performance requirements that must be met to establish initial certification of PM CEMS' ability to demonstrate a facility is in compliance with emission limits. It is different from performance specifications for gaseous pollutants for several reasons. First, the type and characteristics of PM aerosols in stack gas can vary from source to source. Some PM CEMS, such as light scattering-based CEMS, are sensitive to such characteristics as particle size changes, water droplets, dissolved and suspended solids within droplets, stack gas velocity changes, etc. Secondly, PS-11 is different because EPA-approved PM standard calibration aerosols are not available to independently certify a PM CEMS' in-stack response function. Thirdly, PM aerosols are different from other gaseous pollutants because a significant fraction of PM can be lost in the sampling and transport components of a PM CEMS.

A key component of PS-11 is a calibration procedure based on simultaneous M5 and PM CEMS measurements over a range of concentrations. This initial correlation test (calibration) is performed to develop a relationship between PM CEMS' response and the manual reference method (M5) results over a range of PM concentrations. A minimum of 15 valid runs must be conducted, each consisting of simultaneous PM CEMS and M5 measurements covering the full range of PM concentrations. It is important to note that this initial correlation test is not an independent check of accuracy, but an on-site calibration of the PM CEMS that is dependent on the aerosol characteristics at the time of the tests at the specific facility. It is this initial correlation test that is so onerous, due to the need to attain a range of in-stack PM concentrations that are only obtained by modifying normal plant operations. It is this characteristic of PS-11 that is proposed for modification in the proposed alternative method (PS-11B) outlined in Subsection 4.2.

Procedure 2 establishes minimum requirements for evaluating the effectiveness of PM CEMS quality control (QC) and quality assurance (QA) procedures, and assesses PM CEMS data quality by estimating data accuracy. One relevant tool in P-2 used to perform this function is a relative correlation audit (RCA). The RCA is similar to the initial correlation test in PS-11 except only 12 simultaneous M5 test runs are required in P-2, instead of the 15 test runs required in PS-11. Initial correlation tests are required at the time the PM CEMS is installed whereas RCAs are required to be performed periodically as defined by regulations over the lifetime of the CEMS.

The following outlines of proposed alternative specification (PS-11B) and procedure (P-2B) focus on modifications to the initial correlation tests and on-going RCA tests and assume most other aspects remain as stated in the original specifications and procedures.

4.2 Proposed Alternative: Performance Specification 11b

As noted earlier, off-line QAG calibrations of BAM-based PM CEMS cannot be used alone to accurately and reliably predict in-stack response functions for PM CEMS. However, as established in Subsection 3.3, the in-stack response function slope (m) could be determined if the ratio of CEMS probe deposit

(C_c^{PD}) to CEMS reported concentration (C_c) could be determined; i.e. m = 1+ C_c^{PD}/C_C. It is this realization that forms the basis of the following outline for a proposed alternative performance specification to PS-11.

Outline for Proposed Alternative PS-11B

Alternative performance specification (PS-11B) might consist of the following five modified steps to the initial correlation tests:

1. Perform an off-line independent certification of the PM CEMS linear range using QAG-generated reference aerosols at the site (e.g. CFPP) of PM CEMS installation.

Independently certifying the linear range of the BAM-based PM CEMS using a QAG-generated reference aerosol has the potential to establish the linear range well beyond the emission limit without requiring modification of plant processes and is independent of the original thin-film calibration of the BAM-based PM CEMS. The QAG reference aerosol concentrations will be collected from four (4) distinct ranges: <10%, 20-40%, 50-70%, and 80-120% of the PM CEMS' span or PM emissions limit. At least four (4) QAG data points per concentration range, for a total of 16 data points, should be performed for initial certification.

2. Determine probe and transport losses

Determine the "k" constant (C_c^{PD}/C_C) for stack gas at typical operating conditions for the EGU and PM CEMS being tested. This 'k" factor is relatively constant as a function of concentration, as evidenced by the high degree of linearity of the BAM-based PM CEMS demonstrated both with the QAG and M5 correlations.

The "k" factor can be determined either directly by measuring the probe deposit or by multiple simultaneous paired M5 and PM CEMS measurements (M5 = total, C_c^{PD} = total - C_C). The total number of simultaneous tests will depend on the specific acceptance criteria determined for alternative PS-11B.

3. Calculate the in-stack response function.

Calculate the in-stack response function based on data collected in steps 1 and 2, where the slope (m) equals 1+k (m = 1+k)

4. Perform <u>independent certification</u> of the BAM-based PM CEMS in-stack response function using simultaneous M5 measurements.

Complete 3 runs of M5 by collecting PM data from a full stack traverse at normal, "as found" operating conditions. The number of traverse points for each stack is determined based on stack diameter and shape (circular versus rectangular), as described in EPA Method 1. Using the response function determined in Step 3, calculate the average PM CEMS concentration and uncertainties during the time of M5 traverse measurements and compare the two results.

5. Compare intercept of M5 results to the QAG PM CEMS results.

   If the two results are within one standard deviation of each other, make no adjustments to the calculated response function. If it is outside these limits, but within three standard deviations, adjust the intercept to match the M5 results. If these results differ by more than three standard deviations, repeat steps 1 - 4. Additional acceptance criteria will be defined as the alternatives are further developed.

The remainder of alternative PS-11b would be essentially the same as stated in the original PS-11.

4.3 Proposed Alternative: Procedure 2B

The key modification to P-2 in the proposed alternative Procedure 2B (P-2B) is the replacement of the current RCA tests with the same five steps noted in the PS-11B outline above, except there will be 12 repetitions across the linear concentration range (Step 1). This on-going QA/QC certification test would be performed on the same schedule as the current P-2 test schedule.

4.4 Evaluation of Proposed Alternative Methods

Additional PS-11 datasets for MSI BetaGuard PM CEMS are available, as noted in Subsection 2.3, Table 2. Results from QAG testing of three MSI BetaGuard PM CEMS at the BMPS determined that there was very little difference in the off-line, QAG-based response functions; i.e. coefficients of determination for all three PM CEMS were greater than 0.985 and the slopes were within ±2% of each other. Because of the similarity in the QAG measurements of these three PM CEMS, which were manufactured at different times, it is reasonable to assume the factory calibrations for the other 13 PM CEMS, for which we have PS-11 data, would also be similar. As such, it is possible to apply PS-11B to these 13 sets of PS-11 data to demonstrate the application of the proposed model and alternative PS-11B.

Table 6 summarizes key aspects of the PS-11 and PS-11B comparison. The entirety of the application of proposed alternative PS-11B to previously collected PS-11 data is provided in Appendix A of this report. The PS-11 data was provided by MSI, the manufacturer of the BetaGuard PM CEMS. The PS-11B data was calculated using steps similar to the five steps outlined for PS-11B in Section 4.2. The steps applied to the MSI data are summarized below:

Step 1. Except for those PM CEMS where QAG data was collected (CEMS 1A, 2B, and 3A), the off-line CEMS response was assumed to equal the average slope of the three BMPS PM CEMS (1.06x – 1.43), as described in the first paragraph of this section.

Step 2. The probe/transport loss constant (k) was calculated by determining the probe deposit as the difference between individual, paired PM CEMS and M5 or M5B concentration measurements (normal operating range assumed). The “k” value was then calculated by dividing the probe deposit amount by the PM CEMS concentration. (Note: the slope of the in-stack PM-CEMS response function is estimated from a measurement of the probe and transport PM deposit relative to the CEMS-measured PM concentration (C_c^{PD}/C$_C$); that is m=1+C_c^{PD}/C$_C$.). The

individual k-values were then averaged to create the k-constant for use in the next step of this process.

Step 3. The in-stack slope (m = 1 +k) was calculated using the formula defined in Section 3.3 of this report. The intercept (b) was evaluated using three approaches: 1)b set equal to zero, 2) b set equal to the offline QAG intercept, and 3) b defined by the M5 measured concentration at normal operating conditions. The in-stack concentration using the calculated slope with b=0 and b=M5 normalized were similar and best matched the PS-11 value. The percent errors in the predicted concentration at the emission limit in Table 6 were calculated using the zero intercept option.

Step 4. The independent certification of BAM-based PM CEMS in-stack response function was simulated using the true concentration calculated in Step 3. The standard deviation for each concentration was estimated, and the difference between the M5 (PS-11) concentration and PS-11B concentration was determined.

Step 5. The results from Step 4 are compared to the PM emission limit for each CFPP to see if EPA criteria are met.

Table 6. Comparison of PS-11 & PS-11B Calibration Correlations For 14 BAM-Based PM CEMS [a]

Example	Slopes						% Error of PS-11b Slope from PS-11	PM Emission Limit at CFPP	% Error in the Predicted Conc. at the Emission Limit
	PS-11			PS-11b					
1	2.053	±	0.095	2.130	±	0.352	3.7	9.9	0.8
2	2.297	±	0.083	2.575	±	0.190	12.1	9.9	-2.3
4	1.805	±	0.042	1.903	±	0.203	5.4	53.2*	-3.2
5	1.263	±	0.107	1.019	±	0.204	19.3	6.9*	12.4
6	1.462	±	0.045	1.333	±	0.104	8.8	55.5*	4.8
7	1.529	±	0.058	1.433	±	0.117	6.3	11.8	4.8
8	2.665	±	0.134	2.392	±	0.334	10.2	29.0	8.2
9	1.355	±	0.088	1.163	±	0.134	14.2	27.0	14.7
10	1.488	±	0.054	1.430	±	0.224	3.9	37.8*	3.3
11	3.702	±	0.125	3.698	±	0.455	0.1	182.6*	-0.3
12	1.845	±	0.114	1.896	±	0.197	2.8	43.1*	-2.6
13 (1A)[b]	1.169	±	0.025	1.180	±	0.060	0.9	97.9	-0.6
14 (2B)[b]	1.194	±	0.043	1.078	±	0.079	9.7	94.4	8.6
15 (3A)[b]	1.626	±	0.054	1.321	±	0.149	18.7	93.2	21.7
						Avg.	7.9		3.7
						StDev.	5.7		6.0
						% RSD	72		164

[a] Example 3, which was presented in Tables 3 and 5, was omitted from this table because of excessive uncertainty in the slope (40%) and results were more than 5 SD from the mean.

[b] These examples are BetaGuard PM CEMS from the BMPS with individual off-line QAG measurements.

* Emission limit was estimated as 125% or highest PS-11 reading.

Table 6 compares the correlation slopes obtained with PS-11 to those obtained with PS-11B, as well as the slopes' uncertainties and percent uncertainties at each plant's emission limits. The average percent error or difference between PS-11B- and PS-11-determined slopes was 8.3%, with a range of 0.1% to 19.3%, and for all but one case, CEMS 3A, falls within the sum of one standard deviation of each parameter. The average percent error in the predicted concentration at the emission limit is only +5% and ranged from a low of -3.2% to a high of +21.7%, which places all of the slopes within the EPA's P2 ± 25% limit. Although this data is far from definitive, it is encouraging and strongly supportive that PS-11B is a viable candidate for an alternative to PS-11.

The QAG-based PS-11B has the advantage that it would not require extrapolation to the emission limit and it would eliminate the need to modify normal plant operations and aerosol characteristics as is the case during performance of PS-11 and P-2. In addition, PS-11B is likely to have less pollution associated with its implementation and is expected to be easier and lower cost to implement.

4.5 Summary of Benefits of Proposed Alternatives

In order to gain acceptance by the EPA, a newly proposed method should be:

- More stringent than the currently used method,
- Provide a stronger data set with higher statistical strength,
- Improve the "ease of use" for the plant to demonstrate compliance, and/or
- Provide data of equal strength, but with improved and lower costs.

We propose that the suggested alternative methods for PS-11 and P-2 using an off-line QAG calibration have strong potential to meet several, if not all, of these criteria. Firstly, the off-line QAG data is capable of challenging the PM CEMS over a much broader linear range than is possible under the current PS-11. In conjunction with the improved concentration range, the QAG method increases ease of use by not requiring plant modifications in order to meet linear range requirements. Due to the precise, accurate, and quantifiable aerosols produced by the QAG, as demonstrated in the field, the QAG method is anticipated to provide linear results that meet much more stringent acceptance limits than the +/- 25% that is currently accepted by the EPA in P-2. It is unclear at this time if the newly proposed method will provide cost savings; however, it would eliminate the need to modify or shut down normal operations during performance of PS-11 and P-2, which would translate to cost savings for the EGU.

Although our current knowledge of BAM-based PM CEMS functioning in EGUs suggests that an off-line certification with a QAG cannot be accomplished without knowledge of the probe and transport loss constant, the collection of appropriate data and calculation of the correction factor is not anticipated to be cumbersome. In addition, the calibration of the CEMS can be certified by minimal Method 5 runs, instead of the 12 or more runs required by the current procedures.

5.0 Conclusions and Recommendations

A model has been developed that describes a linear relationship between BAM-based PM CEMS measured concentrations and 1) QAG-generated reference aerosol concentrations, and 2) M5 measured stack gas aerosol concentrations. Key components for this proposed linear model include 1) a slope whose deviation from 1.0 is due primarily to probe deposits and 2) in-stack BAM-based PM CEMS response functions that can be determined using off-line QAG-generated reference aerosols and in-stack measurements at typical stack conditions.

This report outlines alternatives to PS-11 and P-2 that do not require altering plant processes. These alternatives meet most, if not all, of the criteria for approval of alternative methods by the EPA.

Based on the encouraging results from QAG testing of the three BAM-based PM CEMS installed at BMPS and the successful application of the proposed model to fourteen BAM-based M CEMS' data sets, it is recommended that an alternative performance specification (PS-11B) and on-going performance procedure (P-2B) be further developed and formalized. Once formalized, it is recommended that these alternatives be submitted to the EPA to solicit their comments and contributions to the development of a field demonstration plan. It is further recommended that the field demonstration tests be conducted to confirm the theories presented in this report. Finally, a report supporting a request for the EPA to approve the alternative PS-11B and P-2B should be submitted after further field demonstration tests are conducted.

6.0 References

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